INEEL/CON-04-02244
PREPRINT

Safety Assurance For Irradiating Experiments In The Advanced Test Reactor

T. A. Tomberlin
S. B. Grover

November 14-18, 2004

International Topical Meeting on Operating Nuclear Facility Safety; American Nuclear Society Embedded Topical Meeting - "Applying Worldwide Experience to Improve Safety and Performance of Nuclear Facility Operations"

Safety Assurance for Irradiating Experiments in the Advanced Test Reactor

T. A. Tomberlin and S. B. Grover

Idaho National Engineering and Environmental Laboratory
2525 North Fremont Ave.
Idaho Falls, ID 83415
E-mail: tat4@inel.gov
E-mail: sbg@inel.gov

Abstract-*The Advanced Test Reactor (ATR), located at the Idaho National Engineering and Environmental Laboratory (INEEL), was specifically designed to provide a high neutron flux test environment for conducting a variety of experiments. This paper addresses the safety assurance process for two general types of experiments conducted in the ATR facility and how the safety analyses for experiments are related to the ATR safety basis. One type of experiment is more routine and generally represents greater risks; therefore, this type of experiment is addressed in more detail in the ATR safety basis. This allows the individual safety analysis for this type of experiment to be more standardized. The second type of experiment is defined in more general terms in the ATR safety basis and is permitted under more general controls. Therefore, the individual safety analysis for the second type of experiment tends to be more unique and is tailored to each experiment***.**

I. INTRODUCTION

I.A. Background

The Advanced Test Reactor (ATR), located at the Idaho National Engineering and Environmental Laboratory (INEEL) is the world's premiere test reactor for performing high neutron flux, large volume, irradiation test programs. With a thermal power rating of 250 MW, the ATR is the largest operating United States Department of Energy (DOE) reactor. The ATR base program, under the authority of the DOE Office of Nuclear Energy, Science, and Technology, assures that other programs using the ATR will have reliable facilities well into the future. The reactor and associated facilities are well maintained and upgraded continually, further assuring researchers that long term programs can be completed.

The ATR is a light water, low temperature, and low pressure test reactor. Light water serves as both neutron moderator and primary coolant, and beryllium is used as a reflector.

Figure 1 is a simplified diagram of the reactor showing typical pressure vessel penetration areas, available experiment handling hardware, etc.

Additional information pertaining to the ATR (and associated experiments) is provided in a "Users Handbook for the Advanced Test Reactor."[1]

I.B. Experiment Categories

The ATR is designed to accommodate two general types of irradiation experiments. The predominant type is a pressurized water loop (PWL) experiment that circulates water, at typical pressurized water reactor pressures and temperatures, past specimens being irradiated in the reactor core. Heat generated in the specimens is transferred to the circulating water, which in turn, transfers the heat in heat exchangers located in a shielded cubicle external to the reactor. The standard PWL experiment utilizes an "in-pile tube" that extends from the reactor pressure vessel top head down through the bottom head, with the circulating water entering and exiting the in-pile tube at the bottom head. A simplified schematic diagram of a PWL experiment is shown in Figure 2. Larger diameter irradiation spaces have been installed for PWL experiments by utilizing a "cross arm" with a pressure vessel penetration through the side of the vessel near the top of an in-pile tube (such that circulation water enters and exits the ATR pressure vessel at two separate locations rather than the same location in the bottom head as is done in a standard in-pile tube). PWL experiments have been characterized over many years of experience and the ATR safety basis relies on a comprehensive set of analyses of these experiments.

The other general type of experiment is a "capsule" experiment. Capsule experiments exhibit greater design

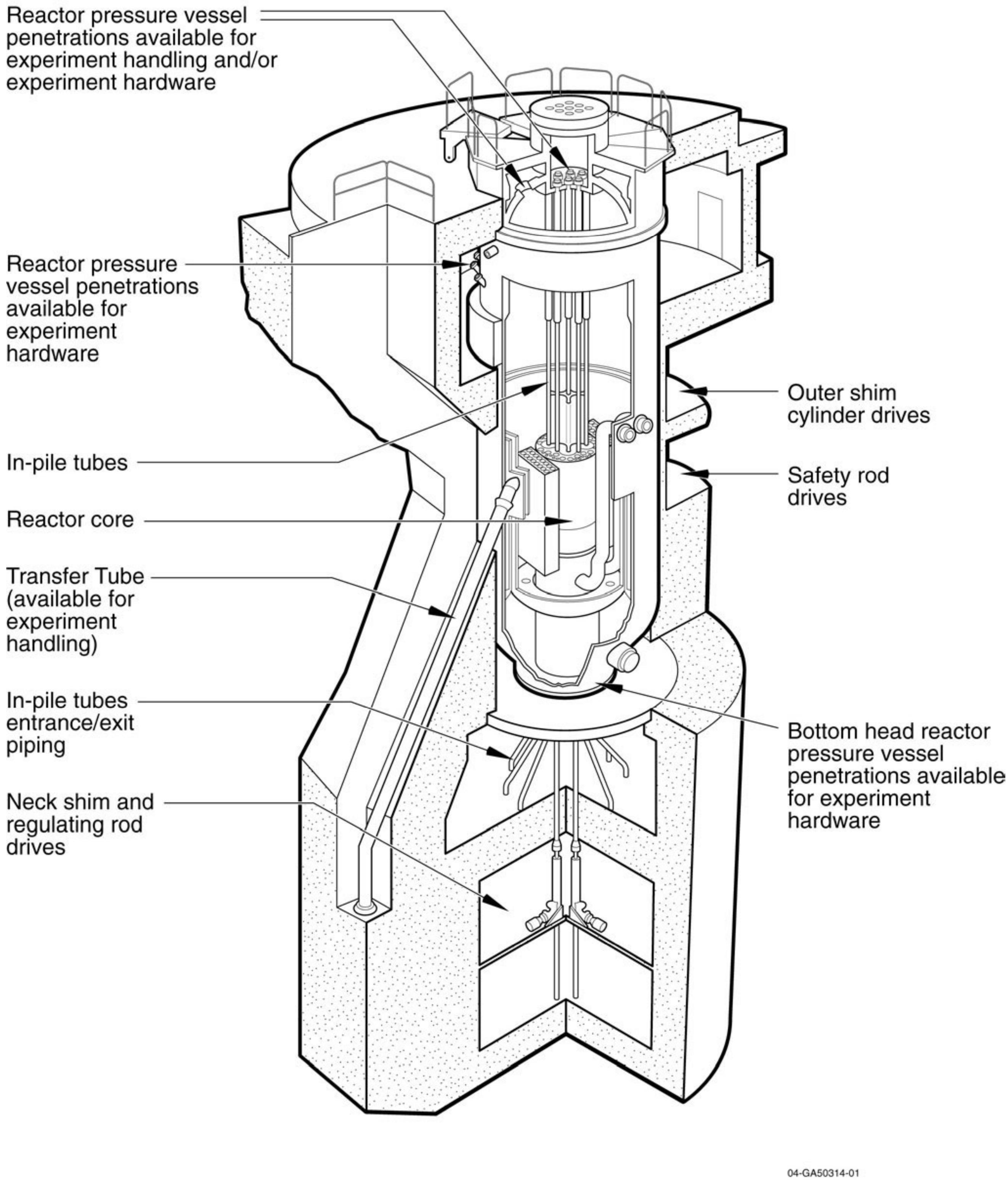

Figure 1. Advanced Test Reactor.

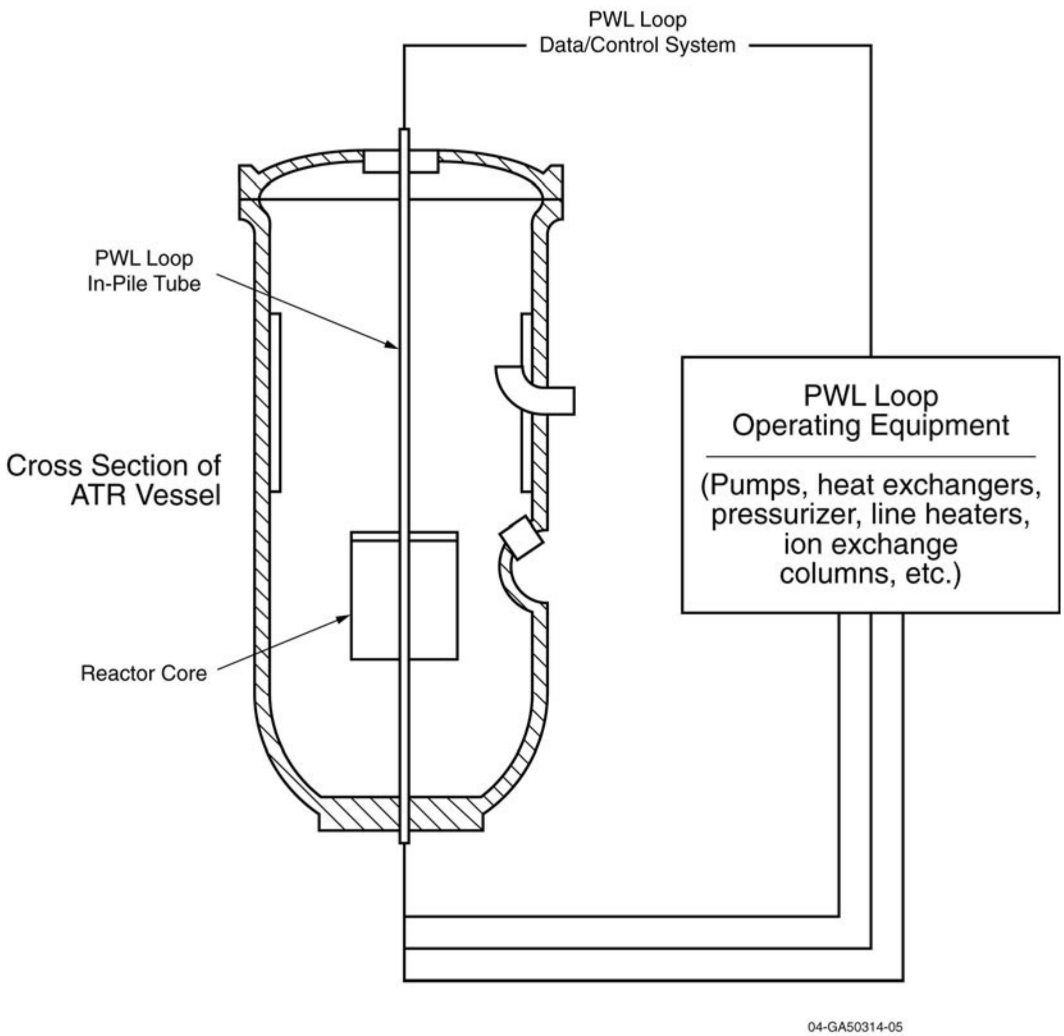

Figure 2. PWL Experiment Schematic.

variations than the PWL experiments and are distinct from PWL experiments primarily in that they rely on reactor primary coolant for heat dissipation. By controlling the heat dissipation from capsule experiments, the experiment target material temperatures can range from approximately the inlet temperature of the reactor primary coolant ($\leq 51.7^\circ$ C) up to temperatures, for example, on the order of 1100° C. Capsule experiments may either be a "drop-in" type (encapsulated and isolated within the reactor pressure vessel as shown in Figure 3) or an "instrumented lead" type (with both instrumentation and gas line leads penetrating the reactor pressure vessel as in Figure 4). Instrumented lead capsule experiments, with variable gas mixtures flowing around the target materials, allow for on-line temperature control of target materials.

A cross section of the ATR core, showing experiment irradiation locations, is shown in Figure 5. The ATR includes 40 fuel elements arranged in a serpentine shape. This arrangement of the reactor fuel results in 9 neutron flux trap regions in a 3 x 3 array. Five (designated in Figure 5 as NW, N, W, SW, and SE) of the nine flux trap regions are currently used for PWL experiments. The flux trap designated as NE is currently used for capsule experiments identified as MICE (Multiple Irradiation Capsule Experiment). Figure 5 also shows the C, E, and S flux trap regions with 7 irradiation positions (1.58 cm diameter) in each region. These regions are currently designed for capsule experiments. Other irradiation positions within the flux trap regions are designated as inboard and outboard "A" positions and "H" positions. The temperature and void reactivity coefficients are negative in the ATR fuel and moderator but are generally positive in the flux trap regions. Safety assurance reactivity issues, for example, can be quite different for experiments, depending on the locations of the experiments and experiment design details.

The unique ATR control system includes 16 vertical control drums (outer shim control cylinders in Figure 5) that rotate neutron poison/reflector materials toward or

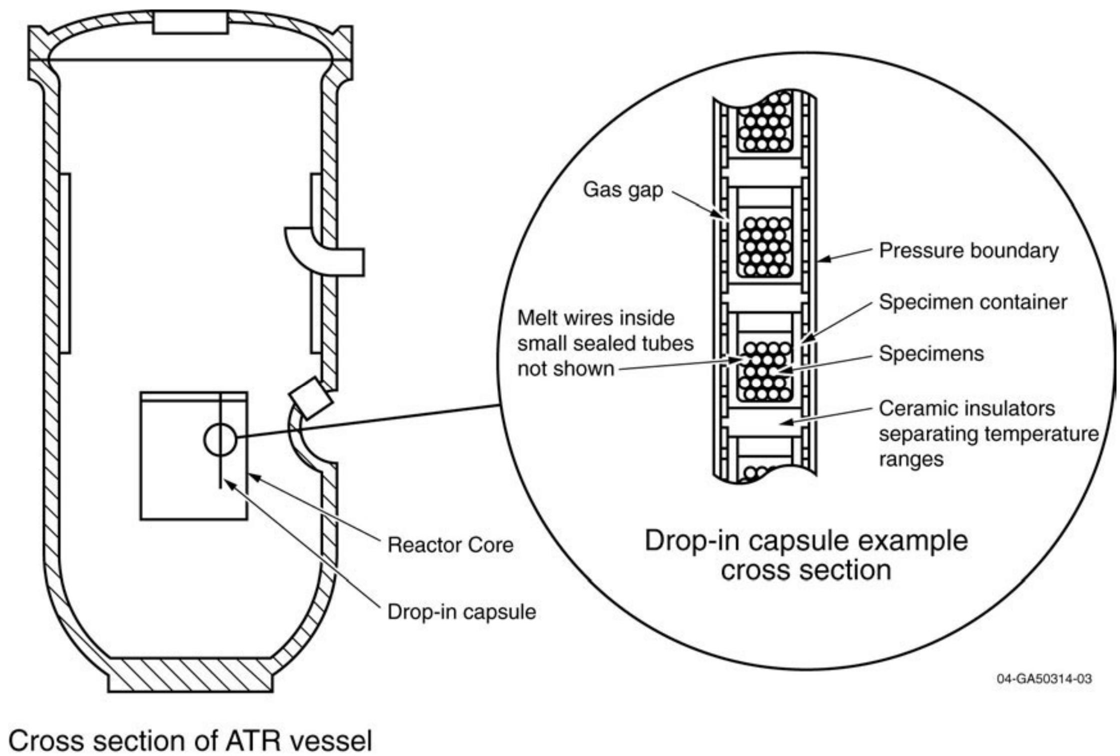

Figure 3. Drop-in Capsule Experiment.

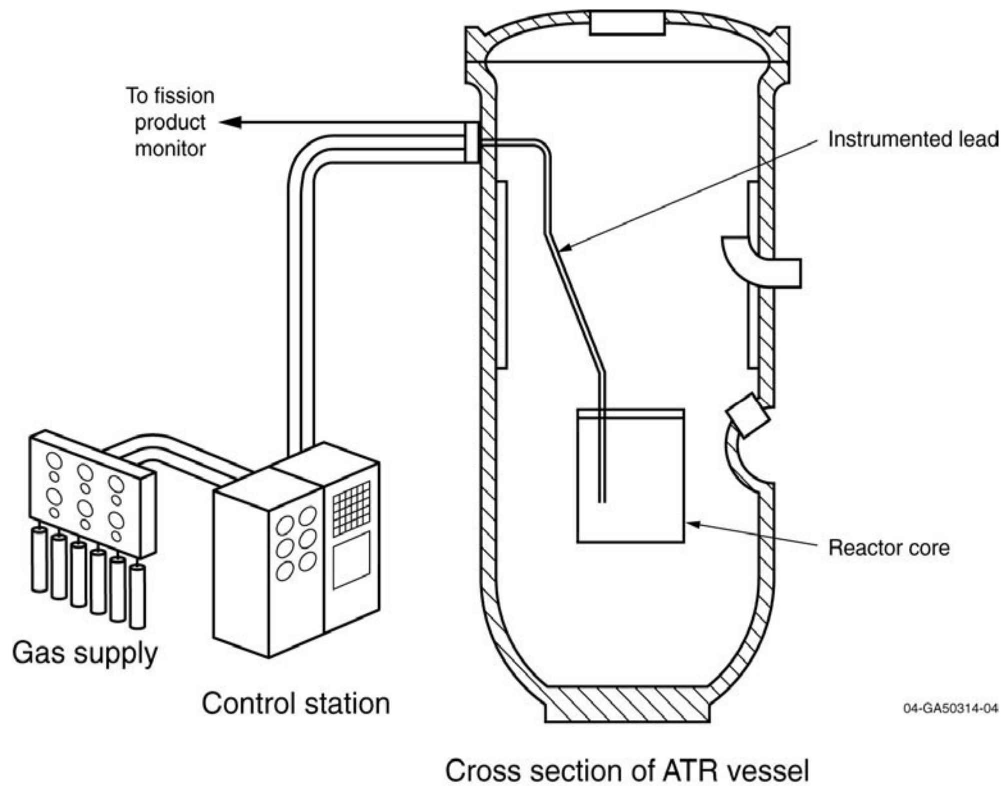

Figure 4. Instrumented Lead Capsule Experiment.

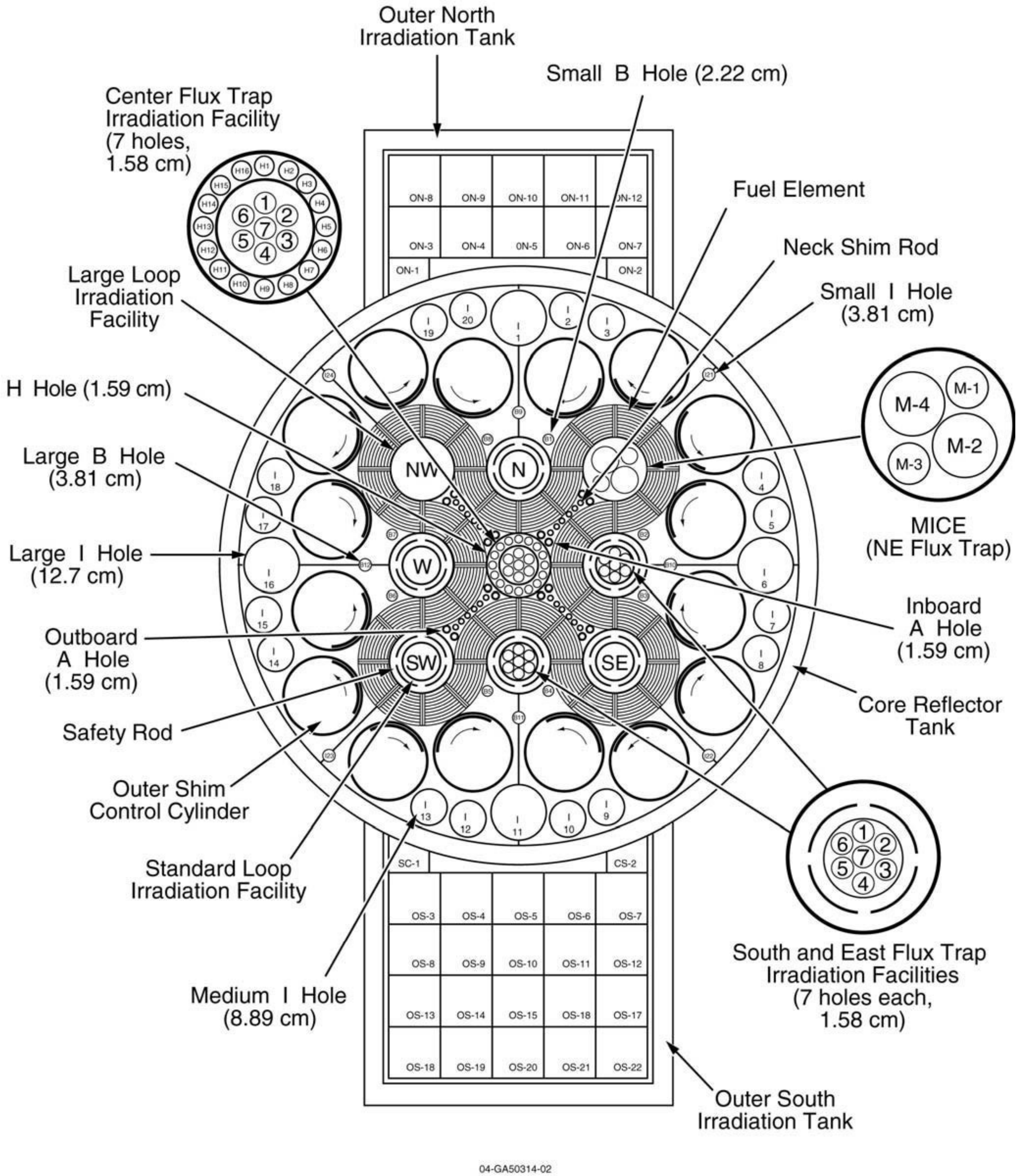

Figure 5. ATR Experiment Irradiation Locations.

away from the reactor core. This system provides an essentially symmetrical neutron flux profile about the horizontal mid-plane of the core throughout each reactor operating cycle and over the duration of experiment programs requiring years of irradiation. Other control components in the core region include 22 neck shim rods, 2 regulating rods, and 6 safety rods. Experiments are not to interfere with the normal operation of these control elements.

Each ATR operating cycle is initiated using a combination of new and partially spent fuel elements. The specific location of the selected fuel elements, along with the control capabilities of the outer shim control cylinders and neck shim rods, makes it possible to operate the ATR at separate power levels in the different flux trap regions. These different power levels, or power divisions, can result in significantly different nuclear environments for experiments, depending of course on the irradiation positions of the experiments.

I.C. Experiment Safety Assurance Package

The ATR has many capabilities and a wide variety of experiments are performed in it. Therefore the safety analyses required to ensure safe operation of each experiment, as well as the reactor itself, can be complex. The analyses applicable to the safety of each experiment are summarized in a packet referred to as the "Experiment Safety Assurance Package" (ESAP). The ESAP addresses the reactor physics, thermal, hydraulic, stress, seismic, vibration, radiological, and all other analyses necessary to ensure the experiment can be irradiated safely in the ATR. The requirements for reactivity worth, chemistry compatibilities, pressure limitations, material issues, etc. are specified in the ATR Technical Safety Requirements (TSR) and the Safety Analysis Report (SAR) for the ATR. Each applicable requirement in these documents is addressed in the ESAP, and supporting documentation (i.e. analyses, evaluations, etc.) is referenced to demonstrate how the experiment complies with the requirement. If necessary, mitigating features such as reactor power limitations, additional safety systems, double encapsulation design, etc. must be provided to reduce the consequences of any postulated accidents to acceptable levels and therefore ensure safe irradiation of the experiment in the ATR. The ESAP is prepared and then submitted for several levels of review and approval prior to the project being granted permission to insert the experiment in the reactor.

II. DESCRIPTION OF THE EXPERIMENT SAFETY ASSURANCE PROCESS

II.A. General Safety Analysis Considerations

The current ATR safety basis establishes the risk envelope for operating the reactor, including operation of the experiments within the reactor. General safety analysis considerations must therefore include recognition that postulated reactor accidents can impact an experiment and conversely, postulated experiment accidents can impact the reactor. Postulated experiment accidents must, whether or not they impact the reactor, exhibit consequences within the risk envelope for the reactor. A proposed experiment that would be outside of the existing reactor risk envelope would require a change to the reactor safety basis. A change to the reactor safety basis to expand the risk envelope would require review and approval by the DOE. Not all conceivable experiments can be described in the reactor safety basis and therefore, as part of the experiment safety assurance process, each experiment is assessed relative to the risk envelope for the reactor per the Code of Federal Regulations 10 CFR 830 requirements for unreviewed safety questions (USQ). 10 CFR 830 requires application of the USQ process in situations where there is a "test or experiment not described in the existing documented safety analysis."[2]

The current ATR safety basis has been developed to provide flexibility in being able to accommodate a variety of experiments. Part of this flexibility has been achieved by defining several "Plant Protection Criteria" that must be satisfied during the irradiation of an experiment. A fundamental function of the ESAP is to demonstrate compliance to the "Plant Protection Criteria."

The "Plant Protection Criteria" limit direct radiological consequences and potential damage to plant barriers that prevent or mitigate radiological releases. They are divided into four categories (Condition 1, 2, 3, and 4) that address a range of conditions from normal operational events to extremely unlikely faulted conditions. They are abbreviated, for illustrative purposes, as follows:

- Condition 1 (Normal operation) – Radiation exposure limits of: 1.00 mSv/year effective dose equivalent (EDE) and 0.10 mSv/year EDE from airborne release to off-site public and 0.05 Sv/year total effective dose equivalent (TEDE) to workers. Reactor fuel source term protection limit: The integrity of the reactor fuel cladding is not challenged except for limited clad defects.

- Condition 2 (Anticipated faults) – Radiation exposure limits of: 5 mSv/year TEDE to off-site public and 50 mSv/year TEDE to workers. Reactor fuel source term limit: No rupture of the reactor fuel plate cladding is allowable unless the clad failure is the initiating fault. For canal accidents no melting of the fuel plate cladding is allowed.

- Condition 3 (Unlikely faults) – Radiation exposure limits of: 62.5 mSv whole body and 0.75 Sv thyroid dose to off-site public and evacuating workers (excluding personnel considered directly at the location of the accident). Reactor fuel source term limit: No large releases of uranium or fission products to the reactor primary coolant system will occur.
- Condition 4 (Extremely Unlikely faults) – Radiation exposure limits of: 0.25 Sv whole body and 3.00 Sv thyroid dose to off-site public and evacuating workers (excluding personnel considered directly at the location of the accident). Reactor fuel source term limit: The reactor primary coolant pressure boundary must be maintained (unless this failure is the initiator) and the reactor confinement must not be damaged.

The predominant risk associated with the ATR is the radiological source term contained within the reactor fuel. The ATR safety basis includes a comprehensive set of accident analyses that include different reactor fuel-related releases. Since most individual experiments include relatively small radiological source terms relative to that represented by the ATR core, it is often possible to demonstrate compliance to the Plant Protection Criteria by making simple fissionable material mass comparisons between the two.

II.B. Safety Assurance Throughout All Experiment Phases

A total safety culture demands safety assurance throughout all experiment phases. The experiment irradiation phase generally represents the greatest risk, however, other phases must not be overlooked. Experiment components often include fissionable materials that must be stored and handled during experiment fabrication or assembly. The associated fabrication or assembly may take place in a facility or location outside the ATR and therefore be subject to a different safety envelope. Criticality safety issues, for example, need to be addressed during assembly as well as storage of experiments containing fissionable materials. Post-irradiation conditions can also present unique safety issues that must be addressed. Adequate post-irradiation cooling of experiments is a typical matter to consider, both for experiment storage and experiment shipping. In a general sense, experience has proved the necessity of a procedural requirement for "cradle-to-grave" safety assurance of all phases of an experiment, both prior to and following the actual experiment irradiation.

Experiment sponsors and project personnel change from experiment to experiment and experiment designs may be developed by engineers not routinely associated with the ATR. In addition to potential lack of detailed knowledge of the ATR and its accident scenarios, experiment project personnel are typically predisposed to thought processes in "success space," rather than "failure space." For these reasons, experience has shown that it is important to involve ATR safety analysis personnel throughout all phases of new experiment design development. Safety analysts, predisposed to thought processes in "failure space," can sometimes provide insights to help guide experiment designs such that last minute surprises are precluded or minimized when the experiment safety analyses are actually conducted and documented in the applicable ESAP.

Safety assurance for the irradiation phase in the ATR requires not just the assessments documented in the individual experiment ESAPs, but also on another safety document that is prepared for every reactor operating cycle. This document is identified as the Core Safety Assurance Package (CSAP) and it is developed to assure safe performance of the reactor given every installed experiment, the specific reactor fuel loading, the projected reactor cycle power divisions, and the projected cycle length. The CSAP demonstrates, among other things, that the reactor control devices will meet specified reactivity requirements, that the nominal excess reactivity is acceptable, and that the fuel will perform within specified limitations. The CSAP recognizes the reactor sensitivity to the PWL type of experiments and establishes corresponding reactor power split limitations to assure safe operation throughout the projected cycle. In general, the CSAP addresses reactor safety given the total effects of all installed experiments, whereas the ESAPs address experiments individually. The combination of the CSAP and all applicable ESAPs assures safe operation of the reactor and the experiments being irradiated during each reactor cycle.

II.C. Experiment Safety Assurance Package Requirements

A management control procedure is used to provide guidance for the preparation and approval of each ESAP. This control procedure requires the ESAP to include the "cradle-to-grave" concept of addressing all phases of an experiment and it specifies the minimum requirements for the outline of the ESAP. Descriptions of the minimum outline subjects, with some additional information, are as follows:

II.C.1 Scope

The “Scope” section of an ESAP is to provide a brief discussion of the purpose of the ESAP along with the scope of activities encompassed by the ESAP. The facilities to be involved are to be noted, along with the activities to be performed within the facilities. Pre-irradiation and post-irradiation activities may involve facilities other than the ATR and a “cradle-to-grave” experiment assessment needs to address all the associated activities. Due to scheduling challenges there are occasions when the scope of an ESAP must be initially limited to initial phases of an experiment program, e.g., limited to just the receipt of an experiment. The scope can then be revised when additional assessments and analyses are developed to support additional steps in the experiment program.

II.C.2 Hazard Classification

When an experiment is inside the ATR facility (not necessarily in the reactor vessel) the hazards associated with the experiment are generally enveloped by the reactor hazard. During experiment activities outside the reactor facility, however, the reactor hazard and associated controls do not apply and experiment hazards need to be recognized. Prior to irradiation, many experiments do not represent hazards other than routine industrial hazards. Some experiments, on the other hand, may include fissionable or other radioactive material, may require machining of pyrophoric materials such as zircaloy, may contain liquid metals that react with air, or may include other features requiring appropriate hazard controls prior to irradiation. Following irradiation, many experiments naturally represent significant radiological hazards that need to be identified and controlled. ESAP hazard classifications of experiment activities serve to assure that hazards are identified and appropriately controlled.

II.C.3 Process Description

Each ESAP is required to include a flowchart as part of the experiment process description. A flowchart is an important tool that helps to assure that all experiment process steps are recognized and assessed for accident conditions. It also helps to provide order in an ESAP and facilitates definition of process boundaries and applicable safety envelopes. The safety envelope during irradiation of an experiment is different, for example, than the safety envelope during movements of the irradiated experiment outside of the ATR.

A written description of each experiment process step is expected to include information pertaining to the physical location, applicable facility, materials involved, and equipment to be used. Also to be included are applicable procedures, individual tasks, pertinent facility and experiment parameters and any associated alarm or mitigating action setpoints, special personnel requirements, and any associated hazards with the step being addressed.

The ESAP process description is to include the governing safety envelope for each identified process step. Different process steps frequently have different safety envelopes and it is important to recognize the differences. A safety envelope typically consists of the applicable facility controlling safety documentation. The safety envelope for irradiating an experiment consists of the ATR Safety Analysis Report and Technical Safety Requirements, whereas the safety envelope for shipment of the irradiated experiment may consist of the applicable Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC) safety documentation for the chosen shipping container (e.g., could be a Type A container versus a Type B).

II.C.4 Demonstration of Compliance

The fourth section of the ESAP is to demonstrate that an experiment complies with the applicable safety envelope requirements. This demonstration of compliance is typically expected to consist of tables of applicable requirements with associated statements that demonstrate how each requirement is satisfied. Although this part of the ESAP is not actually safety analysis, it does assure that applicable safety analysis commitments and technical safety requirements are not overlooked. For experiments processed in the ATR, the aforementioned management control procedure lists the minimum set of commitments and requirements that must be included in the “Demonstration of Compliance” section of the ESAP. Discussions of several types of these commitments and requirements are presented as follows.

Detailed fissionable material constraints are imposed as technical safety requirement administrative controls to assure nuclear criticality safety during fueled experiment handling and storage. Criteria are defined to establish when an experiment is in approved fuel storage and specific limitations are imposed for experiment handling when the experiment is outside of approved fuel storage. Demonstration of compliance for fueled experiment handling will typically include citations of the specific written procedures that implement the requirements. Nuclear criticality safety associated with fueled experiments in the ATR core is assessed as part of the CSAP that accounts for all fissionable material during insertions and removals from the core.

One aspect of accounting for potential impacts of an experiment on the reactor safety is assessment of the potential effects on the axial neutron flux profile that occurs in the ATR fuel during reactor operation. The

ATR safety basis is built around a given axial neutron flux profile that changes as the fuel depletes. To assure that the reactor remains within its analyzed safety basis, it is necessary that no experiment be allowed to cause any significant change to the axial neutron flux profile. Demonstration of compliance to this requirement often requires a physical measurement of the axial neutron flux profile with a given experiment, or representative mockup of the experiment, installed in the Advanced Test Reactor Critical (ATRC) facility. The ATRC is a replica of the ATR that can be used to verify certain nuclear parameters of an experiment before it is installed in the ATR.

The reliability of experiment containment boundaries is an important safety issue. Experiment containment that experiences an internal pressure of greater than 1.62 MPa or that contains material that can generate pressure pulses greater than 2.96 MPa must have a design that meets the intent of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Class 1 standards (prototype testing or other approved means may also be used to demonstrate the experiment boundary will not fail during service conditions). It is not uncommon for experiments to experience internal pressures well below these threshold values. Consequently, the associated containment boundaries are often not designed in accordance with ASME B&PV Code, Section III requirements. In such cases, however, it becomes necessary to demonstrate in the safety analysis section of the applicable ESAP that the consequences of containment failure will be acceptable when the probability of failure is considered as anticipated.

The Demonstration of Compliance section of an ESAP also includes a number of constraints related to experiment materials. These material constraints are directed toward assuring safety of the experiment and the reactor, both during normal operation and during accident conditions, especially accidents in which the experiment containment boundary fails and internal materials become exposed to the reactor primary coolant water.

For fueled experiments, it is necessary to assure that the experiment will not melt when forced coolant flow is terminated and during experiment handling. It is therefore necessary to determine the associated minimum time for which coolant flow must be maintained following reactor shutdown. In some cases no continued forced coolant flow may be required and in some cases an extended decay time beyond flow termination may be needed to assure that an accidentally dropped experiment will not melt. The demonstration of compliance to this requirement will often be documented by specifying in the ESAP the required minimum time that the given experiment must remain in its irradiation position in the reactor before it is allowed to be moved to the adjoining water-filled storage canal.

Post-irradiation handling of experiments at some point includes handling of shipping containers, some of which can cause significant damage if dropped. Therefore, a number of requirements pertaining to cask lifts are part of the Demonstration of Compliance section of each ESAP.

PWL experiments include in-pile tubes that are subjected to demanding conditions. The combination of radiation damage, relatively high pressures, and elevated operating temperatures gradually leads to degradation of in-pile tube materials. Therefore, fast neutron fluence and creep strain limits, for example, are required. Demonstration of compliance is documented for these requirements prior to each reactor operating cycle.

A comprehensive set of enveloping analyses for safe operation of PWL experiments is included as part of the ATR safety basis. Demonstration of compliance requirements also include comparisons of proposed PWL operations with the enveloping analyses to assure that each PWL experiment is operated within the safety basis for each reactor cycle. One comparison includes, for example, the potential reactivity insertion due to voiding in a PWL in-pile tube.

Experiments frequently involve the use of gases inside the experiment containments. Therefore, the potential for gas leakage into the reactor vessel exists. A specific Demonstration of Compliance requirement assures that potential gas leakage into the reactor is assessed and shown to meet the aforementioned Plant Protection Criteria. Gas passing through the reactor core in unexpected locations can result in different consequences depending on the volume of gas and the location. Gas passing through the ATR fuel elements can, for example, cause a heat transfer crisis, whereas gas passing through a flux trap region can cause a positive reactivity insertion.

Capsule experiments rely on reactor primary coolant water for their heat rejection. Although PWL experiments do not rely on cooling by reactor primary coolant, the outer surfaces of the PWL in-pile tubes are in contact with reactor primary coolant. One of the most fundamental requirements for capsule experiments (and the PWL in-pile tube surfaces in contact with the reactor primary coolant) pertains to the assurance that no flow instability will occur during a flow decrease caused by a loss of all operating primary coolant pumps during reactor operation. This type of accident is anticipated to occur as a result of a loss of off-site power (ATR primary coolant pump motors utilize commercial electrical power). A loss of primary coolant pumps results in an immediate reactor shutdown and a decrease in reactor primary coolant flow. As the primary coolant pumps coast down, the emergency pumps maintain primary coolant flow, but at a significantly reduced flow rate.

Two different types of heat transfer crises could potentially occur during this transient and therefore the requirement is divided into two parts. The first part of the requirement is that the departure from nucleate boiling (DNB) ratio is always greater than two (or that the heat flux at the hottest spot is lower, by at least three standard deviations, than the DNB heat flux computed for the condition) during the flow transient. The second part of the requirement is that the rise in bulk reactor primary coolant temperature along the experiment (or PWL surface in contact with reactor primary coolant) hot track is less than half the value that would cause flow instability (or the highest reactor primary coolant temperature is lower, by at least three standard deviations, than the value that would cause the flow to become unstable) during the flow transient. A very conservative approach to this analysis is achieved by assuming either the maximum rated power for the reactor at the beginning of the transient or by assuming an initial reactor power that is significantly above the maximum operating power level that will be allowed during irradiation of the experiment.

The "Demonstration of Compliance" section of each ESAP complements the actual safety analysis to assure that a minimum list of applicable experiment safety issues are consistently addressed from experiment to experiment.

II.C.5 Safety Analysis

The actual safety analysis for each ATR experiment is to be documented in a safety analysis section of each ESAP. The safety analysis is to address at least the most limiting postulated event for each of four probability levels and is to demonstrate that the ATR Plant Protection Criteria (see previous abbreviated descriptions) will be satisfied throughout all ATR steps of the experiment process. Experiment steps not taking place within the boundaries of the ATR facility may, of course, have different applicable acceptance criteria for consequences of postulated accidents.

The comprehensive set of PWL experiment accident analyses documented in the ATR safety basis typically makes it possible for the safety analysis section of each individual PWL experiment ESAP to easily demonstrate that the experiment falls within the existing safety envelope.

The radiological source terms associated with capsule experiment accidents are typically small in comparison with the different source terms associated with the ATR safety basis assessments regarding accidents involving the ATR fuel. Therefore, fueled capsule experiment accidents are often compared to ATR fuel accidents by merely comparing fissionable material masses.

The safety analysis for each capsule experiment is tailored to the experiment. Typically the safety analysis is expected to address a variety of reactor abnormal operating conditions including, for example, such items as reactor overpower and overpressure (110% and 120%). The accident conditions for capsule experiments are varied but almost always involve some human error related events.

II.C.6 Unreviewed Safety Questions

Each ESAP is required to include a section that addresses the Unreviewed Safety Question (USQ) issue. Typically this section states the conclusion regarding the issue and references the specific USQ evaluation (or screening) that supports the conclusion.

II.C.7 ESAP Conclusions

Each ESAP is required to include a recommendation as to whether the experiment, as presented in its process steps, should be conducted. The recommendation is basically a conclusion regarding the acceptability of the risk for conducting the experiment.

II.D. Experiment Safety Assurance Package Development

ATR experiment engineering or experiment project personnel are usually responsible for development of designated ESAPs. Early involvement of nuclear engineering personnel familiar with the ATR safety basis and experiment safety issues is usually encouraged. Experience has shown that involvement of ATR experiment engineering and safety analyst personnel early in the development of experiment designs contributes to successful development of ESAPs and conduct of experiments.

Development of all the supporting analyses for conducting a given experiment is usually an iterative process. There are some analyses, however, that must be finalized before other analyses can be completed. Successful ESAP development hinges around recognition of the critical analysis sequences that are required. One typical analysis sequence that occurs is as follows. The detailed experiment design forms the basis for performing the neutron and gamma heating analysis during reactor operation. The results of this analysis become inputs for thermal-hydraulic analyses of the experiment. The results of the thermal-hydraulic analyses then feed into stress analyses that are needed to demonstrate adequate experiment containment. Thermal and reactivity analyses can be tied together, for example, in cases involving experiments located in the reactor flux trap regions.

Successful ESAP development and conduct of an experiment can also hinge on determining early in experiment development whether or not physical measurements will be required in the ATRC facility. These nuclear measurements can be long lead time items.

The level of conservatism used in analyses supporting experiment safety assurance packages may vary depending on the nature of the experiments. Some experiments are clearly more simple and benign than others and may warrant less conservatism in the associated analyses. In some cases, such as the coast down of primary coolant flow described in Section II.C.4, the level of conservatism is prescriptive.

II.E. Experiment Safety Assurance Review and Approval

ESAPs are typically authored by engineers familiar with the experiments being addressed. The authors are frequently involved in the development and/or analyses of the experiments.

A peer review of each ESAP is typically performed by an engineer in the ATR experiments engineering organization. In addition to the required peer review, a review is required by the ATR nuclear safety engineering organization. This review is typically performed by an experienced engineer familiar with the ATR safety basis and experiments conducted in the ATR. Each ESAP must also be given line management approval by the ATR experiments organization.

Final approval of each ESAP is based on review by an independent safety review committee composed of members with a variety of technical backgrounds and nuclear experience. This committee has a high level of authority and broad review coverage relative to the operation of the ATR. Approval by this committee is required before any experiment can be irradiated.

III. CONCLUSIONS

Experience has shown that application of the safety assurance methodology described in this paper has supported the safe operation of a wide variety of experiments in the Advanced Test Reactor over a period of many years.

ACKNOWLEDGMENTS

This work was supported by the United States Department of Energy (DOE) under DOE Idaho Field Office Contract Number DE-AC07-99ID13727. The authors express gratitude to D. L. Combs and J. K. Patton for graphics support and text processing support in preparing this material.

REFERENCES

1. "Users Handbook for the Advanced Test Reactor," Idaho National Engineering and Environmental Laboratory, INEEL/EXT-02-01064, 2002.
2. 10 CFR 830, "Nuclear Safety Management," *Code of Federal Regulations*, Office of the Federal Register, January 2001.